A New Compact Size Microstrip Patch Antenna with Irregular Slots for Handheld GPS Application

Jawad K. Ali*

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Abstract

A new reduced size single probe fed microstrip patch antenna with irregular slits has been presented to be used as a receiving antenna for Global Positioning Systems (GPS) integrated with cellular handheld mobile wireless systems. The proposed design is based on the nearly square microstrip patch antenna with two pairs of orthogonal slits cut from the edge. It has been found that this antenna offers further reduction in size with good radiation properties required for GPS system. The resulting circular polarization bandwidth (with axial ratio ≤ 3 dB) has been found to meet that required for this application. The proposed antenna possesses an average gain of 4.5 dB overall the GPS L1 operation.

Keywords: GPS Microstrip Antenna, Antenna Miniaturization, Circular Polarization, Axial Ratio.

الخلاصة

في هذا البحث تم اقتراح تصميم لهوائي جديد مصغر الحجم لغرض استخدامه في اجهزة استقبال منظومات ايجاد الموقع العالمي (GPS) التي يمكن ان تكون متكاملة مع منظومات الاتصال اللاسلكية المحمولة يدويا. ان التصميم المقترح مبني على اساس هوائي الشريحة الدقيقة المربع تقريبا ذي زوجين من الفتحات المتناظرة المتعامدة التي يتم قطعها من حافات المربع. جرى في التصميم المقترح قطع زوجين من الفتحات المتعامدة غير المنتظمة لتحقيق التصغير الاضافي في ابعاد الهوائي المقترح. وجد ان التصميم الجديد يقدم تصغيرا اضافيا في حجم الهوائي مع محافظته على مواصفات البث اللازمة لعمل منظومة (GPS) ، حيث ان حزمة النطاق الترددي للأستقطاب الدائري (لنسبة استقطاب محوري اقل من dB 3 ملائم لتغطية النطاق الترددي المطلوب لعمل منظومة (GPS) . لقد وجد ايضا ان معدل قيمة كسب الهوائي المقترح هي بحدود dB 4.5 على كامل النطاق الترددي المطلوب وهي قيمة مناسبة لعمل المنظومات المدنية العاملة بالتردد (L1:1.57542 GHz).

Introduction

Size miniaturization of the normal microstrip patch antenna has been accomplished by various forms which include the use of high dielectric constant substrates, modification of the basic patch shapes, use of short circuits, shorting-pins or shorting-posts; or a combination of the above techniques.

Employing high dielectric constant substrates is the simplest solution, but it exhibits narrow bandwidth, high loss and poor efficiency due to surface wave excitation [1]. Modification of the basic patch shapes allows substantial size reduction; however, some of these shapes will cause the inefficient use of the available areas. Shorting-posts were used in different arrangements to reduce the overall dimensions of the microstrip patch antenna. These shorting-posts were modeled and analyzed as short pieces of transmission lines with series inductance and shunt capacitance [2].

Compact microstrip antenna can also be obtained by embedding suitable slots with variety of shapes in the radiating patch. Variety of microstrip patch antennas with a wide range of slot shapes that are suitable for achieving compact circularly polarized radiation or compact dual frequency operation with orthogonal polarization had been reported in [3].

In this paper, a probe-fed nearly square microstrip patch antenna with two pairs of irregular slits has been presented

Department of Electrical and Electronic Engineering, University of Technology

as a candidate for use in a handheld GPS antenna. The slit dimensions had been optimized to satisfy the compact size and the required radiation characteristics for GPS L1 antenna operation.

The Proposed Antenna

By embedding suitable slots in the radiating patch, compact operation of microstrip antennas can be obtained. Figure 1.*b* shows slotted patch suitable for the design of compact microstrip antenna. In this figure, the embedded slot is a cross slot, whose two orthogonal arms can be of unequal [4] or equal lengths [5]. This kind of slotted patch causes meandering of the patch surface current path in two orthogonal directions and is suitable for achieving compact circularly polarized radiation or compact dual-frequency operation with orthogonal polarizations [6].

The basic idea of the proposed antenna structure has been extracted from a comparative study of both the conventional square patch antenna, Fig. 1*a*, and the square microstrip antenna with two pairs of orthogonal slits at the edges, Fig. 1*b* [7]. The presence of slits in this antenna is a way to increase the surface current path length compared with that of the conventional square patch antenna, Fig. 1*a*, resulting in a reduced resonant frequency or a reduced size antenna if the design frequency is to maintained. It had been found that this antenna structure provides a reduction in size of about 40%.

In the present work, further increase in the slit lengths has been proposed in an attempt to gain further size reduction of the resulting structure as compared to the patch structures cited in Fig.1*a* and 1*b*. Because these slits are originally cut from the patch edges, the extra lengths added to these slits are achieved by changing its shapes. As shown in Fig.1c the slits now have irregular structures .The dimensions of each pair of slots have been optimized to meet the GPS antenna design requirements. A single 50 Ω probe feed has been used to support producing the RHCP requirement of the GPS antenna radiation pattern. The location of this probe has found to be dependent on the slits dimensions.

The Proposed Antenna Design

The calculations of the square microstrip antenna length are based on the transmission-line model [8]. The width *W* of the radiating edge, which is not critical, is chosen first. The length *L* is slightly less than a half wavelength in the dielectric. The precise value of the dimension *L* of the square patch has been calculated using the expression [8,9]:

$$L = \frac{c}{2 f_0 \sqrt{\varepsilon_{eff}}} - 2\Delta L \qquad (1)$$

where ε_{eff} is the effective dielectric constant and ΔL is the fringe factor.

For a frequency of 1575.42 MHz and using RT/Duroid 6010 LM substrate with a relative dielectric constant of 10.2 and a substrate height of 1.575 mm, this yields the value of the nearly square patch antenna length (Fig.1*a*) of *L* = 29.54 mm. The slit lengths of the antenna in Fig.1*b* are tuned to the resonance (design) frequency in the *x* and *y*-directions and are set to result in a value of about 7.5 mm, with a slot width a of 1 mm. This results in a patch length of the antenna structure of Fig.1b to be *L* = 22.90 mm, using the same substrate. The resulting size reduction offered by this antenna is of about 40% as compared with the conventional nearly square microstrip antenna.

The proposed antenna structure has been modeled using the HP HFSS 5.3 software from EEsof [10]. The modifications of the slit shapes have been inserted in this structure. The dimensions of the modified antenna structure have been optimized using the HP Empipe3D software from EEsof [11]. Empipe3D enables the designer to designate geometrical and material parameters as candidate variables for optimization.

Using the 3D graphical tool within HP HFSS one can create a set of incremental changes to the solid model. The information is then processed by Empipe3D to parameterize the structure by means of geometry capture technology. The resulting antenna structure dimensions are shown in Fig.1*c*. In this case, further size reduction offered by this antenna of about 48% as compared with the conventional nearly square microstrip antenna.

Simulation Results

The proposed antenna structure had been modeled at the design frequency of the GPS (L1).It has been supposed that the antenna element to be located parallel to x-y plane and centered at the origin (0, 0, 0).

The computed input return losses of the antenna patch is shown in Fig.2. This does not prevent the possibility of other resonant bands out of this range, since this antenna can be considered as a special case of Minkowski-like pre-fractal antenna which exhibits multiresonance behavior [12].

E-plane RHCP and LHCP radiation patterns at the GPS L1 frequency of 1575.42 MHz are shown in Fig. 3. It is clear that this antenna supports the required RHCP electric field radiation pattern.

The required axial ratio *AR* has been calculated using [13, 14]:

$$AR(dB) = 20\log\frac{E_R + E_L}{E_R - E_L} \quad (2)$$

where E_R and E_L are the right and left handed circularly polarized radiated electric fields. The resulting axial ratio as a function of frequency is depicted in Fig.4. It can be seen that the axial ratio in the broadside direction is below 3 dB throughout a bandwidth of about 10 MHz, which adequately covers the CP bandwidth of 2 MHz required for the civilian GPS L1 application employing the C/A code [15]. The computed gain around the GPS L1 has shown in Fig.5. As the gain response implies, the proposed antenna possesses an average gain of about more than 4 dB throughout the required bandwidth of GPS L1 antenna [15].

Conclusions

A compact multiband single probe-fed microstrip patch antenna with two orthogonal irregular pairs of slots has been investigated. The proposed antenna has shown to possess a size reduction of about 48%, as compared with that of the conventional microstrip patch antenna with adequate radiation characteristics and gain meeting the GPS L1 requirements. The resulting size of this antenna makes it applicable for use in mobile handset application. The realized impedance bandwidths (return loss ≤ −10 dB) and the circular polarization bandwidth (axial ratio ≤ 3 dB) satisfy the bandwidth requirements for the GPS L1 operation.

The proposed design can be generalized by applying the same idea to other applications, where circular polarization and compact design represents ultimate requirements.

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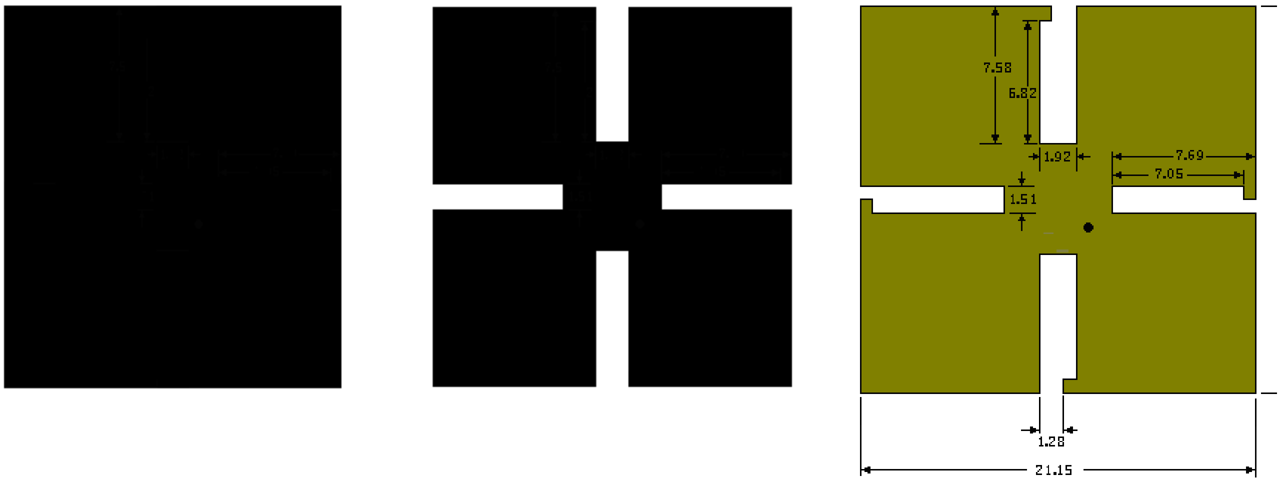

a *b* *c*

Fig.1 (a).The nearly square patch antenna, (b). Nearly square patch antenna with two pairs of orthogonal slits, and, (c). Nearly square patch antenna with two orthogonal pairs of irregular and unsymmetrical slits.

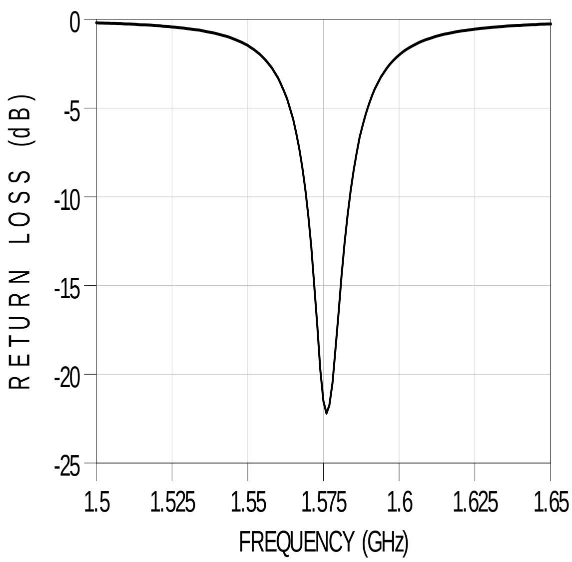

Fig.2 The calculated input return loss for the modeled patch element.

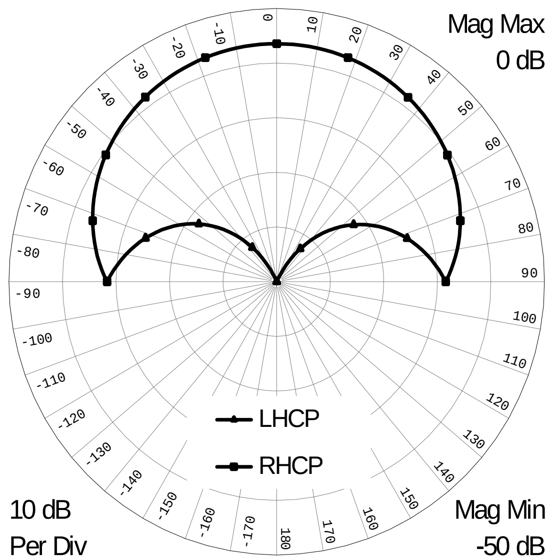

Fig.3 E-plane RHCP and LHCP antenna radiation patterns at 1.57542 GHz

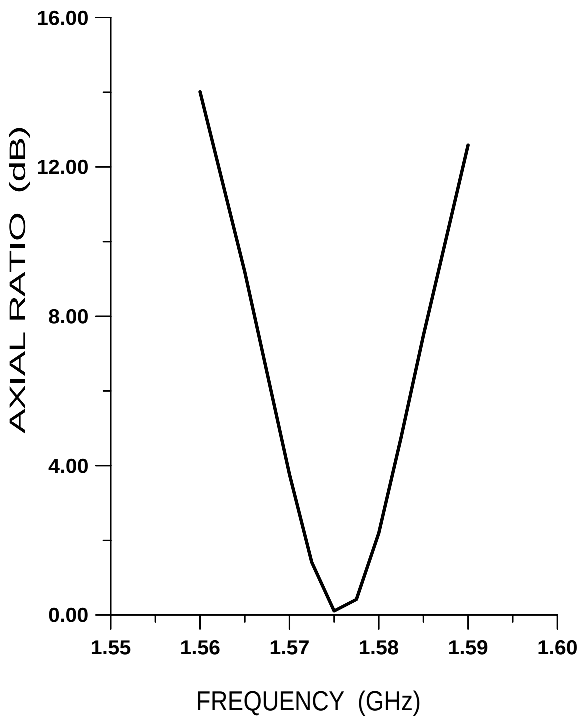

Fig.4 The computed axial ratios around the GPS L1 frequency, for the proposed antenna.

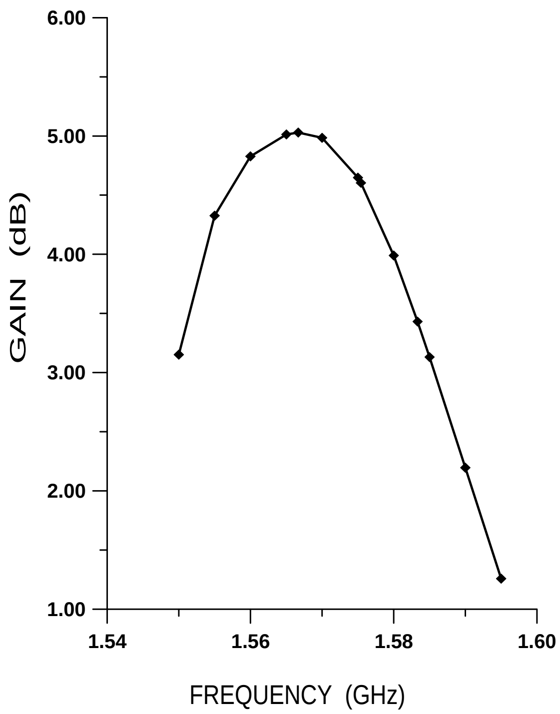

Fig.5 The computed antenna gain around the GPS L1 frequency, for the proposed antenna.